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EP 0833443 A1
JP 060303049 28.10.94. and WPI Abstract Accession No. 1995-01 7571 [03] and PAJ abstract

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(54) Abstract Title
An efficient PWM switched amplifier with variable carrier frequency

(57) An amplifier comprises means for producing a PWM signal from a triangular carrier and an audio signal, switching amplifier means responsive to the PWM signal and means for varying the carrier frequency between a high frequency in the presence of an audio signal and a low frequency when the audio signal is absent. This reduces the quiescent current drain. A two transistor amplifier (fig 1) and a four transistor bridge amplifier (figures 3,4 and 5) are described. A common mode choke (270) may be connected to reduce the passage of the low frequency carrier.

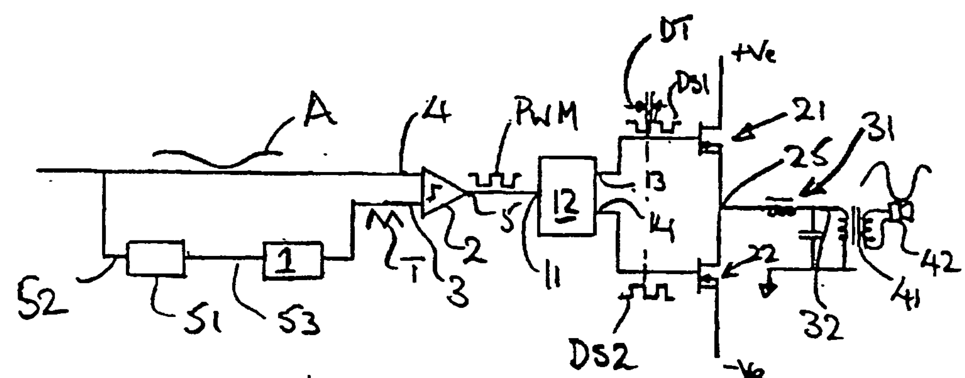

FIGURE 1

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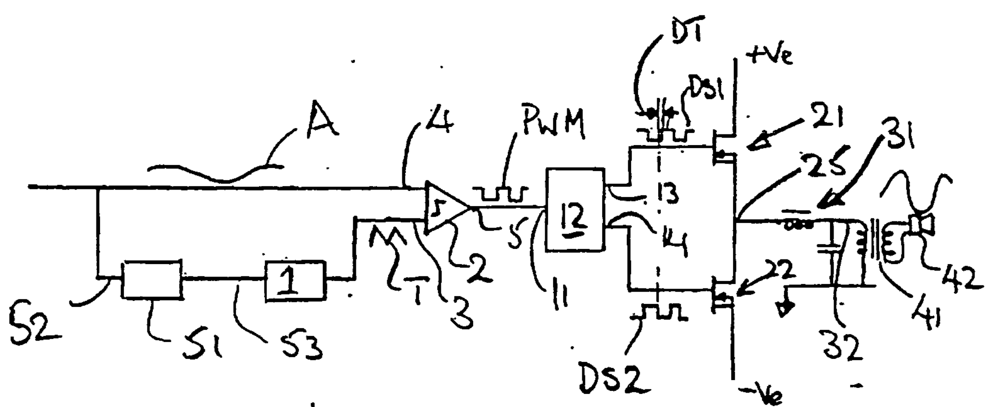

FIGURE 1

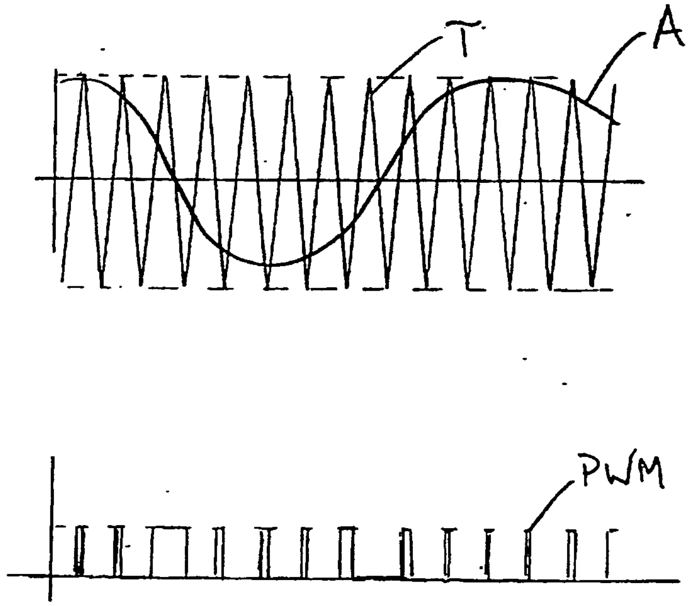

FIGURE 2

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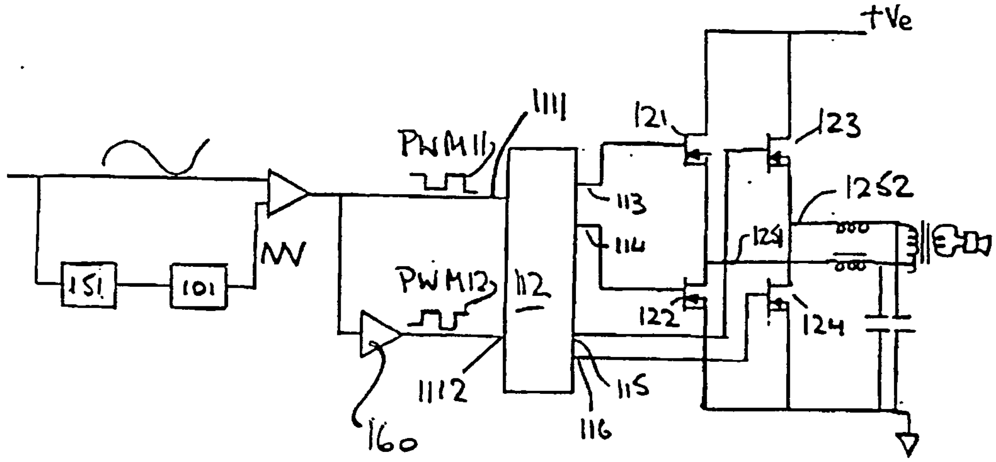


FIGURE 3

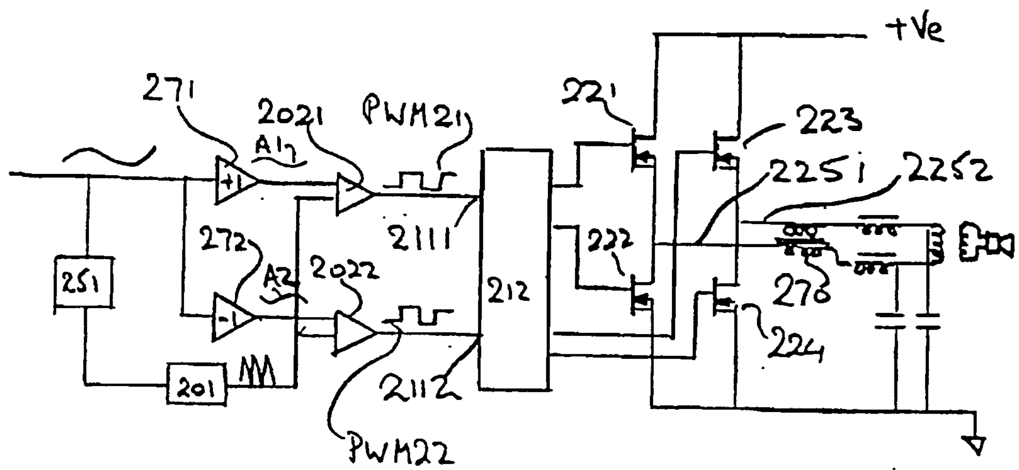
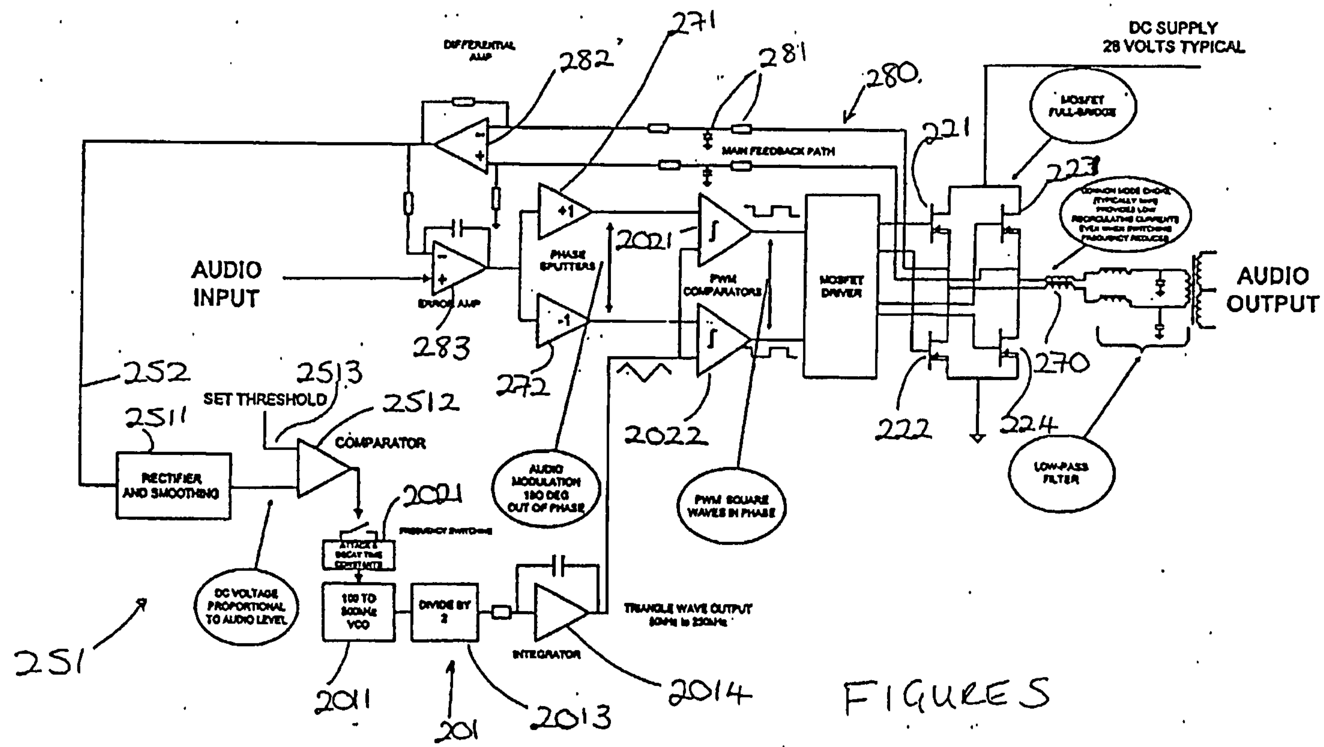


FIGURE 4


DC SUPPLY
28 VOLTS TYPICAL
MOSFET FULL-BRIDGE
DIFFERENTIAL AMP
282
271
281
280
221
223
MAIN FEEDBACK PATH
AUDIO INPUT
AUDIO OUTPUT
ERROR AMP
283
PHASE SPLITTERS
+1
-1
272
2021
PWM COMPARATORS
2022
MOSFET DRIVER
222
224
270
LOW-PASS FILTER
PWM SQUARE WAVES IN PHASE
AUDIO MODULATION 180 DEG OUT OF PHASE
252
2511
2513
SET THRESHOLD
2512
COMPARATOR
RECTIFIER AND SMOOTHING
DC VOLTAGE PROPORTIONAL TO AUDIO LEVEL
2001
FREQUENCY SWITCHING
DIVIDE BY 2
INTEGRATOR
TRIANGLE WAVE OUTPUT
251
2011
201
2013
2014

FIGURES

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Audio Amplifier

The present invention relates to an audio amplifier, particularly for voice evacuation applications.

Voice evacuation systems are mains power driven, with battery back up. The standards typically require that such a system should be able to operate from the battery back-up for half an hour after 24 hours of mains failure. Accordingly the system and its components require to exhibit low quiescent current drains and a high efficiency in operation, in order to minimise the size of back-up battery pack required.

Class D amplifiers using switch-mode techniques are inherently efficient in operation. However they suffer from quiescent losses associated with each switching cycle.

The object of the present invention is to provide an efficient amplifier with a low quiescent current, in particular by slowing the switching frequency when the amplifier is quiescent.

According to the invention there is provided an audio amplifier comprising:

- means for producing a pulse width modulated (PWM) square wave signal, having a carrier frequency and modulated by an audio input signal;
- an audio drive circuit including:
  - at least one transistor device arranged to switch the potential of a switched connection in accordance with the PWM square wave signal,
  - drive means for switching the transistor(s) in accordance with the PWM square wave signal and
  - a low pass filter for filtering the carrier wave from the signal on the switched connection to provide an amplified audio output signal; and
- means for varying the carrier frequency between a high frequency in the presence of the input audio signal and a low frequency in the absence of the input audio signal.

Whilst it is envisaged that the PWM signal production means may be a digital processor, arranged to modulate the pulse width in proportion to the amplitude of the audio signal; this function is preferably performed in an analogue fashion, although some functional blocks may be processor based. Preferably the means for producing the PWM square wave signal comprises:

- means for generating a triangular carrier wave;
- means for combining the triangular carrier wave with the input audio signal to produce the pulse width modulated (PWM) square wave signal.

The reduction in the carrier wave frequency reduces gate capacitative losses in the transistor devices. This is because the losses are associated with each capacitative charge, which occurs each time the device is switched. Reduction in the frequency reduces the aggregate number of charges and the associated losses. It should be noted that the devices are still switched in the absence of an audio signal.

In practice, the high frequency is the conventional frequency for operation of a switch mode amplifier and the low frequency is one at which the amplifier is still operable at low audio input levels, albeit with increased in-band audio modulation products, but which are subjectively inaudible because they are relative to the low audio modulation level. Typically, the reduction in frequency is of the order of five times.

In a simple embodiment, a single pair of transistor devices are provided for switching between one voltage rail of one potential and another of opposite potential or ground with the PWM signal. In the preferred embodiments, four transistor devices are provided in full bridge configuration, with two switched connections, between respective pairs of transistor devices, being switched. This enables drive of the loudspeakers connected to the transistor devices – via the low pass filter – positively with the potential applied in one direction in one half cycle and the potential applied in the other direction in the other half cycle.

Preferably the transistor driving means is a drive circuit having two inputs, one for each pair of transistors at respective sides of the bridge, and two pairs of

outputs, one for each of the transistors of the respective pairs. The drive circuit is adapted to switch one of the transistors ON whilst the other of the respective pair is OFF and vice versa, conveniently with a small period between switching ON when both transistors are switched OFF.

Preferably the transistor devices are MOSFET transistors.

It is envisaged that two alternative arrangements may be provided for driving the transistor driving means. In the first, PWM carrier signal is inverted, by an inversion circuit, to one of the inputs. This results in one of the switched connections being at the applied potential during one half cycle and the other being low and vice versa. Recirculatory current losses can result from the currents flowing in the low pass filter with this arrangement, in particular at the low carrier frequency. The actual losses are due to the associated currents flowing through the finite MOSFET on-resistances

In the second, preferred arrangement, the carrier signal on the inputs are in phase. In order to differentiate them as regards their audio modulation, each is separately constituted from the carrier wave by comparators for combining the triangular wave with the audio signal, the audio signal to one being inverted, by an audio inverter. The result is that switched connections are high or grounded in phase together, at least in the quiescent mode. A common mode inductor, having a winding for each connection, is then preferably provided between the transistors and the low pass filter for isolating the low pass filter from the carrier signal, where the recirculatory losses would otherwise occur.

Preferably the triangle wave generator is a voltage controlled oscillator and associated integrator. The voltage for controlling the oscillator is preferably derived from a comparison of the audio input signal with a threshold value, the arrangement being such that when the audio is low, the voltage from a comparator drives the oscillator at a low frequency and vice versa.

The preferred amplifier is provided with a feed back loop for controlling its gain, and the feed back signal is applied to the comparator of the voltage controlled oscillator.

To help understanding of the invention, specific embodiments thereof will now be described by way of example and with reference to the accompanying drawings:

Figure 1 shows a block diagram of an amplifier according to the invention;

Figure 2 is a plot of an audio and a triangle wave being compared to generate a pulse width modulated signal;

Figure 3 is a block diagram of another amplifier of the invention;

Figure 4 is a block diagram of a third amplifier of the invention; and

Figure 5 is a block diagram similar to Figure 4 but in more detail.

The amplifier shown in Figure 1 has a triangle, carrier wave generator 1 feeding a triangle wave T to a comparator 2 at one input 3; whilst an audio signal A is fed to the other input 4 of the comparator. As shown in Figure 2, the comparator generates a pulse width modulated square wave PWM at it output 5, the PWM signal being high when the audio signal is of greater magnitude than the triangle wave and being low when the audio signal is of lesser magnitude than the triangle wave. The PWM signal is fed to an input 11 of a MOSFET driver 12. This has two outputs 13,14, on which are reproduced the PWM signal, as drive signals with - one DS1 - being inverted with respect to the other - DS2. A double MOSFET bridge 21,22 extends between a positive rail +Ve and a negative rail –Ve. The driver is arranged so that there is a small dead time DT, at the beginning of each high state of the drive signals, in order to avoid both both MOSFETs conducting at the same time. A switched connection 25 between the two MOSFETs 21,22 is connected to a an LC low pass filter 31. A load transformer 41 and a loudspeaker 42 are connected to the output connection 32 of the filter. The components described so far are conventional in a Class D amplifier.

In accordance with the invention, the triangle wave generator 1 incorporates a voltage controlled oscillator, to which an audio level detector 51 is connected. The audio signal A is fed on input 52 to the level detector. Whilst the level is low, the

detector outputs on line 53 a low voltage to the oscillator, which therefore runs at a low frequency. When the audio level is high, the detector changes its output to high voltage and the oscillator operates at high frequency.

When the audio level is low, the triangle wave is generated continuously at the low frequency. The PWM signal also is generated, but is symmetric in the absence of audio. The drive signals DS1, DS2 are also generated and so the MOSFETs 21,22 are continuously switched out of phase with each other. The switched connection 25 experiences equal periods of positive and negative rail voltage with a DC average of zero. The carrier component is filtered by the LC filter and the loudspeaker experiences no audio drive.

The MOSFET devices have a gate capacitance. Application of the drive signals DS1,DS2 charges and discharges the gates in such a way that the charging currents flowing through the MOSFET driver circuitry cause power loss and therefore represent a nett current drain. The current associated with this loss is proportional to the frequency of triangle carrier wave. Thus slowing the frequency at low audio levels reduces the quiescent current drain.

When the audio reaches a significant threshold of audibility, the level detector causes the oscillator to speed up, to a frequency at which the amplifier operates with full fidelity, i.e. a switching frequency sufficiently high that in-band PWM modulation products are negligible. The capacitative gate loss rises, but this is acceptable in operation. During operation, the pulse width of the PWM square wave varies through the audio cycle, whereby the switched connection experiences longer periods of positive voltage during one half of an audio cycle and longer periods of negative voltage during the other half cycle. For instance at the peak of the audio cycle, the connection is switched to one voltage for the greater part of several carrier cycles. The instantaneous voltage on the connection is filtered by the LC filter, which passes the audio signal amplified to a peak to peak voltage of the rails, typically 27V. The transformer increases this at the loudspeaker to around 100V rms.

Turning now to Figure 3, the amplifier there shown has a full bridge of four MOSFT devices 121,122,123,124, in two pairs. For switching these, the MOSFET

driver 112 has two pairs of outputs 113,114 and 115,116. The arrangement is such that within each side of the bridge both of devices 121 & 122 and 123 & 124 cannot be switched on together, and are switched alternately, in accordance with the state of the PWM signals PWM11, PWM12 on the two inputs 1111,1112 to the driver. In a voice evacuation system, the positive rail would typically be 28V DC in accordance with the voltage of the battery back-up supply. The MOSFET bridge in this embodiment extends between a +Ve rail and ground. The amplifier has an additional component in that an inverter 160 inverts the signal PWM12 to the input 1112. In other respects, this amplifier is similar to that of Figure 3, except that it has two switched connections 1251,1252 and the LC filter has its inductive and capacitative components duplicated as well. In particular, the two halves of the bridge are switched in exactly analogous ways, although 180° out of phase as regards the carrier frequency. Thus when the connection 1251 is switched positive, the connection 1252 is switched negative and vice versa, allowing for the dead time. Thus when the amplifier is quiescent, the gate losses are reduced in exactly the same way as in the amplifier of Figure 1. The DC average voltage on the connections will be half that of the +Ve rail. When audio is present, the carrier frequency is raised. The PWM modulation will cause an average voltage on the connections 1251,1252 which differs from the quiescent half rail voltage in opposite directions by the same amount at any one time. Thus there is twice as much voltage available to drive the loudspeaker as there would be if only one side of the bridge were present.

Turning now to Figure 4, this amplifier has an alternative arrangement for applying the PWM signals PWM21,PWM22 to the MOSFET inputs 2111,2112. This is achieved by duplicating the PWM comparators 2021,2022, the triangle carrier wave being fed to both. The audio signal A is applied to two phase splitters 271,272, one of which passes the signal as A1 with its phase unchanged and the other of which passes the signal as A2 with a 180° phase shift. The resultant signals PMW21,PWM22 are in phase as regards their carrier frequency but out of phase as regards their modulation. Thus where one carrier cycle has a longer high level, the corresponding low level in the other signal is longer. The long high level is applied to one side 221,222 of the MOSFET bridge and the long low level is applied to the other side 223,224. Thus the average voltage on one connection 2251 moves in one direction from the half rail

voltage and the average on the other connection 2252 moves in an equal and opposite direction.

In the quiescent state, the voltage on the connections 2251,2252 moves in phase. Connected between them and the LC filter (which is duplicated as in the Figure 3 embodiment) is a common mode choke 270, connected to inhibit passage of the carrier wave at the reduced frequency to the LC filter. Thus recirculatory losses in the latter are minimised in the quiescent state. The audio component of the bridge output is still differential in nature and as such is unaffected by the common mode inductor. This means that the common mode inductor can be given a high value without affecting the audio frequency response of the LC filter

Turning to Figure 5, the amplifier of Figure 4 is shown in more detail. In particular, an audio feed back loop 280, having RC filters 281 for attenuating the carrier, a differential amplifier 282 for combining the signal from the two sides of the bridge, and an error amplifier 283 for combining the feed back signal and the original audio signal A are provided. The input 252 to the level detector 251 is from the differential amplifier 282 via a rectifying and smoothing circuit 2511. The detector includes a comparator 2512 have a threshold input 2513, which is held at an adjustable potential. The comparator output switches between two levels, and is applied to the voltage controlled oscillator 2011 via attack and decay time constant circuits 2012 arranged to ramp the carrier frequency quickly in the presence of audio and reduce it more slowly when the audio ceases. The oscillator runs at an over frequency, which is halved by the divider 2013 to guarantee an exact 50% duty cycle. The square wave signal from the divider is converted to a triangular wave form by an integrator 2014.

In practice it has been found that an operational carrier frequency of 250kHz and a quiescent frequency of 50 kHz provides satisfactory performance, including reducing the current associated with the power loss due to the MOSFET switching by a factor of five typically from 100mA to 20 mA. This was achieved for a 200W amplifier operating from a 28V DC supply. Times of the order of 2msec for ramp up of frequency and 6msec for decay have proved satisfactory with an audio threshold of

40dB below full output. Further, a common mode choke 270 value of 1mH reduces recirculatory losses to an insignificant level.

CLAIMS:

1. An audio amplifier comprising:

- means for producing a pulse width modulated (PWM) square wave signal, having a carrier frequency and modulated by an audio input signal;
- an audio drive circuit including:
  - at least one transistor device arranged to switch the potential of a switched connection in accordance with the PWM square wave signal,
  - drive means for switching the transistor(s) in accordance with the PWM square wave signal and
  - a low pass filter for filtering the carrier wave from the signal on the switched connection to provide an amplified audio output signal; and
- means for varying the carrier frequency between a high frequency in the presence of the input audio signal and a low frequency in the absence of the input audio signal.

2. An audio amplifier as claimed in claim 1, wherein the PWM signal production means is a digital processor, arranged to modulate the pulse width in proportion to the amplitude of the audio signal

3. An audio amplifier as claimed in claim 1, wherein the PWM signal production means is an analogue generator arranged to modulate the pulse width in proportion to the amplitude of the audio signal, preferably including functional blocks.

4. An audio amplifier as claimed in any preceding claim, wherein the means for producing the PWM square wave signal comprises:

- means for generating a triangular carrier wave;
- means for combining the triangular carrier wave with the input audio signal to produce the pulse width modulated (PWM) square wave signal.

5. An audio amplifier as claimed in any preceding claim, including a pair of transistor devices for switching between one voltage rail of one potential and another of opposite potential or ground with the PWM signal.

6. An audio amplifier as claimed in any one claims 1 to 5, including four transistor devices in full bridge configuration, with two switched connections, between respective pairs of transistor devices.

7. An audio amplifier as claimed in claim 6, wherein the transistor driving means is a drive circuit having two inputs, one for each pair of transistors at respective sides

of the bridge, and two pairs of outputs, one for each of the transistors of the respective pairs.

8. An audio amplifier as claimed in claim 7, wherein the drive circuit is adapted to switch one of the transistors ON whilst the other of the respective pair is OFF and vice versa, preferably with a small period between switching ON when both transistors are switched OFF.

9. An audio amplifier as claimed in claim 8, wherein the transistor devices are MOSFET transistors.

10. An audio amplifier as claimed in claim 9, including an inversion circuit, for inversion of the PWM carrier signal, connected to one of the transistor inputs.

11. An audio amplifier as claimed in claim 9, including

- a pair of phase splitters one of which is adapted to pass the audio signal unchanged and one of which is adapted to pass the audio signal with a 180° phase shift,

wherein the means for producing the PWM wave signal is two comparators for producing two PWM signals by combining the triangular carrier wave with each audio signal, such that the two PWM signals are in phase as regards their carrier frequency but out of phase as regards their modulation.

12. An audio amplifier as claimed in claim 11, including a common mode inductor, having a winding for each connection, between the transistors and the low pass filter for isolating the low pass filter from the carrier signal where the recirculatory losses would otherwise occur.

13. An audio amplifier as claimed in any preceding claim, wherein the triangle wave generator is a voltage controlled oscillator and associated integrator.

14. An audio amplifier as claimed in claim 13, including means for comparison of the audio input signal with a threshold value for determination of the voltage of the oscillator, the arrangement being such that when the audio is low, the voltage from a comparator drives the oscillator at a low frequency and vice versa.

15. An audio amplifier as claimed in claim 14, wherein the amplifier is provided with a feed back loop for controlling its gain, and the feed back signal is applied to the comparator of the voltage controlled oscillator.

16. An audio amplifier substantially as hereinbefore described with reference to Figures 1 and 2, Figure 3, Figure 4 or Figure 5 of the accompanying drawings.

The Patent Office

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Application No: GB 9824153.2
Claims searched: 1-16

Examiner: D Midgley
Date of search: 28 February 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H3W WAC,WUE

Int Cl (Ed.7): H03F 1/02,3/217

Other: ONLINE:WPI,EPODOC,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	EP 0833443 A1 (HARRIS) See, for example, the figures	6-12(Y)
X,Y	JP 060303049 (MITSUBISHI) 28.10.94. (See figure 1 and also WPI Abstract Accession No. 1995-017571 [03] and PAJ abstract)	1-5,13-15 at least (X) 6-12 (Y)

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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